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Very great interest has been elicited in the making of hydraulic forgings since it has become evident that some other way than hammering will have to be introduced for the treatment of very large steel castings either for machine or for ordnance purposes.

The hammer has held such an important position in the manufacture of iron and steel for so many years that any fault found with it seems at first unreasonable; yet nothing became apparent more quickly when very large pieces were required for shafting or for ordnance purposes than that the hammer was very inefficient in its action on the metal and often produced defects which weakened the strength of the piece. The rapid blows of light steam hammers often produce flaws where none existed before, while the blow of the heaviest hammer yet made is less efficient than the same force applied as pressure. One of the principal reasons for making forgings is to get rid of blow holes or at least of diminishing the size of the cavities in which the gases are contained, or which are produced by contraction, but the metal when brought under the hammer is often already too cold to make this entirely possible.

The effort to substitute rolls for the hammer has not succeeded. It has been found that while the hammer and the rolls answered very well for small pieces, for very large ones they were entirely inadequate. One of the most striking defects in the casement

plates made for Fort Delaware, in 1868, was, that although made of the very best charcoal iron, they did not stand a single fire, and when they were torn apart by the blow of the shot, no place was found larger than the palm of the hand where the welding was perfect. This was owing to the fact that a partial oxidation of the iron took place before the temperature was raised high enough to do the welding. On the outside such oxide can be easily removed by adding a flux ; on the inside this flux does not reach, and the oxide, if formed, remains to prevent welding. Often it enters the body of the piece seriously affecting its quality, and producing effects which are rarely ever attributed to it. It must also, be borne in mind that the heat, which is sufficient for forging, is not sufficient for welding, and, also, that in large pieces it is quite possible that the heat may be black on the outside, while it is still high in the inside, and vice versa. The consequence is that under the ordinary circumstances of either rolling or hammering, there are both the dangers of absorption of oxygen and defects of welding, to contend with as well as the strains produced by the blow, both of which weaken the iron. Besides this, small surfaces only, are acted upon at a time. With the hammer the shock may be too great on the outside for the temperature, and yet too slight to expel the cinder from the inside, and at the same time the stroke may be too slight for the temperature of the outside to effect the welding, yet the shock may be sufficient, especially at the critical temperature to produce internal strains or even serious defects. The result is that heavy and sudden shocks will very often break welds, independently of any strain which may be produced by want of proper annealing. It is admitted that the so-called fibrous structure of iron is that which makes the material the strongest; that is a tendency to crystallization of such a kind that when the iron is submitted to a strain, the crystals are drawn out rather than separated. The tendency towards this so-called fibrous condition is very much increased by pressure and decreased by repeated shock. The advantage of pressure, if it can be made uniform, is that it works everywhere upon all parts of the iron or steel, and works so slowly that the crystals have time to extend themselves in the direction in which the pressure acts, while with sudden and repeated blows this is not the case. Rolls do excellent service in this direction in a small way, but their action can only be on

very small surfaces at a time, and they have been found to be entirely inefficient in the working of very large pieces.

In the year 1871 Mr. J. Haswell, appreciating these inconveniences of forging iron and steel, and the expense attendant upon the ordinary method of making pieces forged in the blacksmith's shop very much larger than they were required, and then cutting them down with tools, invented a press with a power of 800 tons, to make the various parts of locomotives used by the Austrian R.R., of which he was the engineer. In the year 1873 he made, at the World's Fair in Vienna, a very interesting and important exhibit of the parts of locomotives that had been made in this way, by pressing them into cast-iron moulds. The pieces were made very nearly of the size required for the finished parts, provided they could be delivered from the moulds when they had been pressed into shape. When they could not be delivered, it was only necessary to add a small amount of extra material to some part which was easily removed afterwards with but little comparative waste and expense. It was found that the molds could be made very cheaply, and, if broken, could be easily replaced. The use of this press required that there should be a certain number of forgings of each kind made, which he found by experiment was not less than ten for every piece, in order to make it economical. When more than that were required it was very cheap, the cost being diminished in some cases as much as 50% ; when less, it was too dear to be used.

The iron brought up to red heat was placed upon the molds or swages, and the press brought gradually down upon it, so that every particle of the iron was slowly forced, without noise or jar, into every part of the mold, and came out with the so-called fibrous condition instead of being crystallized. Of course, the molds have to be made so that the forgings can be easily delivered, which requires, in some cases, some superfluous thickness or extension of the parts which can be very easily removed. These forgings are homogeneous, have the so-called fibrous condition, are in such a shape that the iron is even, without annealing, in every part in the strongest possible condition. The work has grown to such an extent that several presses of two thousand tons are now working continuously by this method. The advantage of the forgings thus produced is that they are

strong, have no tendency to crystallization, that they admit of being worked up rapidly and with the greatest economy of both time and labor, and of material as well. But it has always been admitted, up to a comparatively recent period, that such forgings with hydraulic power could be done only upon small pieces, as the efforts to make large pieces had not always been successful. It is remarkable, the articles made by this process are almost always sound, and contain so few local defects that the percentage of loss in the forging is exceedingly small, while their quality is greatly increased.

The recent demand for steel ordnance of heavy weight has directed attention to the many experiments made, noticeably by Whitworth, of Manchester, England, who, for the last twenty-five years, has been experimenting in this direction, and has succeeded in making a quality of steel which for strength and durability is equal to if not superior to any previously made. The striking peculiarity is its homogeneity, not in the sense of being cast from a fluid state, but in the sense of freedom from blow holes and of uniform composition and quality throughout.

I had occasion, in the month of Sept., 1884, to visit the recently-constructed works at Manchester, which are of very large size and arranged with every modern convenience, both for making large and small tools, and to see their methods of measuring with the greatest accuracy very minute quantities, as well as of making the largest size shaftings and guns of the heaviest weight, all of it being done with apparently the same ease. Their methods of obtaining very large ingots free from blow holes and of forging them, are undoubtedly those which must be used in the near future for the treatment of steel in large masses. The experiments which have produced these results were commenced in 1863, and have been continued with great success, but with enormous expense ever since, securing for the inventor the honor of knighthood, in addition to a world-wide reputation, not only for the size and quality, but also for the great accuracy of his work at the same time.

The steel is made in the Siemens-Martins furnace, and is poured in at the top of steel ingot molds, which are cylindrical in shape and cast especially for the purpose. They are built up in sections, which are securely bolted together by means of flanges, the size and number of the sections depending on the length and weight of the piece to be cast.

These molds are fitted with rods on the inside in such a manner as to facilitate the packing of molding sand in the strongest way. The melted steel is let into the ingot mold standing on a truck in front of the furnace. The truck runs on rails placed in the bottom of a trench, which is parallel to the furnaces, and is carried at once to the press. The head of the press is brought down on to the liquid steel and allowed to rest on it without any pressure, except its own weight, being put on it, and is locked in that position. The first effect is a shower of sparks, which, as the mold is closed by the projection on the head, last only a few seconds. The pressure is then very gradually applied from below. It has been found necessary to commence with the pressure as soon as the mold is closed and the head of the press locked, as the gases are all the more easily driven out of the steel as it is more fluid. The maximum pressure is usually arrived at in about half an hour, the time depending on the weight of the casting. This maximum is generally about 13,000 pounds to the square inch. The pressure varies with the amount of ductility required of the metal, the greatest being when the greatest, and the least when the least is required. When the process was being experimented on pressures as high as 20 tons to the square inch were used, but experience has shown that beyond the pressure of about 6 tons, no sensible advantage is gained, and this is now generally adopted for the limits of the heaviest ingots which have as yet been made.

During the time of pressure, gas in large quantities escapes from every aperture in the mold, which at once takes fire and burns on the outside. The volume of the steel diminishes in the course of the first five minutes as much as $\frac{1}{6}$ to $\frac{1}{8}$ of the length of the ingot. Experience has shown that there is no gain in compressing it more than this, but that the maximum pressure must be gradually applied, and that there is no advantage of extending the time even for very large castings much over 35 minutes. After the maximum pressure has been applied it is gradually let down to 1500 lbs. per square inch and kept at this pressure until there is no longer any danger of further contraction of the metal, which, if allowed to act as it would without pressure, might crack in the interior, and thus endanger the strength of the ingot. The forcing out of the gases and the enormous compres-

sion which each particle of the steel undergoes tend to make the ingot more homogeneous, not only preventing the formation of cavities but closing them and welding them together while the steel is in a pasty condition, and probably also preventing to a considerable extent the liquation of the elements which takes place even where steel is cast in small ingots, as recent investigations which I have made to determine this point show. When the ingot has cooled and is sufficiently consolidated to be removed from the ingot mold, the pressure is removed and the ingot is taken out and reheated, unless it is hot enough, to be taken directly to the place where it is to be treated. The method is exactly the same whether a cannon of large calibre is to be made or a shafting of small diameter. The ingots are always cast hollow, and all the forging is done upon mandrils of large size. They are brought under the hammer head, which is pressed down a certain depth and the ingot moved in the swage below from its middle towards one end. At each successive plunge of the head, the steel yields like dough and moves forward towards the end, exactly in the same way. As the movement is slow and without shocks, all the particles move in the same direction. When the movement has been made from the middle towards one end, the pieces are made to move in the other direction. It is generally found that it is best to increase the length of the ingot no more than six feet at a single operation. The ingot then goes back to the furnace, is reheated, and this operation is continued until the requisite form is arrived at. All the forging being done in this way on a mandril and in a die, the pieces are forged with remarkable accuracy.

The press which serves for shaping is made to accommodate itself to any size or form of piece*. By turning the piece round in the die, perfectly uniform results can be obtained as far as the shape of the steel is concerned, while the continued action of the pressure forces the steel to assume the shape which the quick, sharp blow of the hammer could not produce both on account of the exceedingly short time of action, and the elasticity of the piece. The slow penetrating action of the press draws out the crystals and

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* In Vol. X. of the Proceedings of the U. S. Steel Institute there is a description of these presses. Accurate drawings have also been given of both of them in plates [illegible]

makes them assume the direction of the flow. All shocks and consequently all tendency for the crystals to assume large faces are avoided. The small crystals are simply forced to follow the direction which the pressure gives, and to flow continuously without changing their form or their size, their general arrangement only being changed, so that instead of becoming larger or more separated, they tend to become smaller and more closely compacted, which probably is the reason of the high quality of all the steel made by this process.

The method of doing the work, and of making all the pieces hollow, has a decided advantage. It is well known that the centre of all large pieces is an element of weakness, adding nothing to the strength of the piece, but greatly increasing its weight. It is exceedingly doubtful whether by hammering a large ingot can ever be made perfectly sound at the core. Many of the serious accidents which result from the fracture of large forgings have been caused by the propagation of these central defects to the outside when rupture takes place. The center of any very large forging is always an element of uncertainty. By removing it altogether, and forging on a mandrel, the pieces can be made one-third, or even more, lighter and stronger, thus diminishing the quantity of material while increasing its efficiency. Sir Joseph Whitworth claims that in addition to these advantages, the ductility of the steel is easily brought up 30%. All these effects become the more apparent according as the casting is heavier. The method seems to be the only one for treating very heavy castings. The various government commissioners, who have examined the method, have reported in favor of it, and some of the largest works in Europe are now about to adopt it, as the work done by the press could not be done by the hammer at all. The great hammers in use near St. Petersburg, at Essen, and at Creusot, seem to have reached their limit both of size and usefulness. The cost of the foundations increases so rapidly with the capacity of the hammer, and the danger to other structures of striking such heavy and quick blows as are necessary to make such forgings, seem to put them out of the question independently of the effect of the blow on the quality of the steel. A 2,000 ton press, which is entirely independent as a machine and produces no shocks, and requires, therefore, no expensive foun-

dations, is equal in efficiency to an 80-ton hammer, and can do as much work, and do it very much more accurately, than any hammer. It is doubtful whether it would ever be worth while under any conditions, to build a hammer that would be equal in efficiency to the 8 and 10,000 ton presses which are doing the current work of Whitworth's establishment. If we are to have castings capable of turning out 100-ton guns, we must have some other means of treating the steel than the sharp, quick blow of the hammer, which is quite as likely to tear and crack the steel in certain stages, and to produce unnecessary internal strains in all, as to benefit the metal. The press seems to solve the problem.

I saw at the works a hollow crank shaft 58 feet long, 18 inches in diameter, so true, when it came from the press, that when a sixteenth of an inch was removed from the surface the shaft was ready to go into its bearings. It is very doubtful whether so large and true a forging could have been made in any other way. Much larger and heavier shafts have been made, and have been used under circumstances where they would probably have failed if made in any other way. One of these recently finished was 55 feet long, 30.5 inches in diameter, with a hole 14 inches in diameter in its centre, and weighed 48 tons, a reduction in weight of 16 tons, with much greater strength than the solid shaft. A tube for a 110-ton breech loading gun was 42.5 feet long, 27.1 inches in diameter. The centre hole was 14.75 inches in diameter; it weighed 26 tons. If it had been cast solid it would have weighed 40 tons.

Such remarkable results produced with so much certainty, have attracted the attention of our own government. It is doubtful, however, whether such pieces could ever be made, or such a work be managed by any government. It needs the stimulus of private enterprise with government patronage to make success possible. In the first instance private parties would probably be fearful of the results of a new enterprise, and capitalists without the certainty of government orders, would be slow to construct the necessary works, but it needs no gift of prophecy to foretell that in the near future the parts of machinery and of ordnance which must be of great weight to bear very heavy trains, will be constructed hollow and by pressure, so as to remove altogether from the piece the central part where the greatest uncertainty lies.